

## Review Article

# The welfare of pigs during transport and slaughter

Temple Grandin

Department of Animal Science, Colorado State University,  
Fort Collins, CO 80523-1171, USA

### Abstract

To maintain a high standard of animal welfare during the transportation and slaughter of pigs requires both the proper equipment and supervision of employees. The use of numerical scoring of handling and stunning can help maintain high standards because it will enable management to determine whether or not practices are improving or deteriorating. The following variables should be measured: 1) The percentage of pigs stunned correctly, 2) percentage that remain insensible, 3) percentage that are prodded with an electric goad, 4) percentage that fall during handling and 5) percentage vocalizing. For electric stunning, sufficient amperage must be passed through a pig's brain to induce an epileptic seizure. For carbon dioxide, a 90% concentration is recommended. Other gas mixtures are reviewed. Handling facilities must be designed so that pigs move easily without baulking or backing up and have non-slip floors. Research on the following topics is reviewed: electric stunning, carbon dioxide stunning, pig behaviour during handling, return to sensibility, facility design, truck loading, density and transport stress.

### Introduction

I have worked on handling, transport and slaughter of pigs for over 20 years as an equipment designer, behaviour consultant and scientist. To improve animal treatment in the field requires good management. One of my biggest frustrations as an equipment designer was getting people in the slaughter plants to operate the new equipment correctly. Good animal welfare during handling, transport and slaughter requires the following:

1. training and supervision of employees
2. well-designed equipment utilizing behavioural principles and scientifically validated stunning procedures
3. good equipment maintenance
4. equipment must have sufficient capacity for the number of pigs being handled

When a welfare problem occurs during handling, transport or slaughter, one must be careful to diagnose the true cause of the problem. Is it a people problem or an equipment problem? In this paper the author will review scientific studies and reports on observations made during visits to over 100 pig slaughter plants in the USA, Canada, Europe, Australia and other countries. In the USA and Canada, the author has designed and worked on installation and start-up of handling systems in over 25 pork plants. Scientific literature relevant to pig welfare during handling, transport, lairage and stunning will be covered.

### Numerical evaluation of stunning and handling

The first step in maintaining high animal welfare standards is correct operation and maintenance of equipment. A numerical scoring system can help management maintain high standards (Grandin, 2000a). It enables management to determine whether or not their handling and stunning practices are improving or deteriorating and it is less subjective. The variables that should be measured are: 1) the percentage of pigs stunned correctly on the first attempt, 2) percentage of pigs that remained insensible, 3) percentage of pigs that fall down during handling, 4) percentage of pigs prodded with an electric goad and 5) percentage that vocalized (squealed) in the conveyor restrainer (Grandin, 1998). In carbon dioxide (CO<sub>2</sub>) systems, the percentage of pigs squealing when the gondola is loaded is counted. Each pig is scored on a *yes/no* basis on each variable. For example, each animal is either poked with an electric goad or not poked. All scoring is on a per animal basis. After scoring, the percentage of pigs handled correctly on each variable can be calculated. One hundred pigs should be scored. In one survey, electric goad use varied greatly between plants that processed 500 or more pigs per hour through a V-conveyor restrainer. In five plants with well-trained handlers where the goad was only used on pigs that refused to move, the percentage of pigs goaded was 0%, 0%, 18%, 18% and 80% (Grandin, 1998). In two other plants where the handlers were not trained 40% and 48% of the pigs were electric-goaded at the restrainer entrance. After ten minutes of instruction from the author, the percentage of pigs moved with the electric goad was reduced to 15% in both plants. They were still able to keep the processing line full. Numerical scoring can be used to maintain high standards and prevent a slow deterioration of standards that nobody notices.

### Plant survey data

The author observed that great improvements in stunning and handling occurred after large meat-buying customers started welfare audits (Grandin, 2000a). In England, large supermarkets have been auditing plants for years. In 1999 the McDonald's Corporation started scoring both pork and beef plants with the numerical scoring system (Grandin, 2000a).

During 2002, auditors working for McDonald's, Burger King and Wendy's evaluated 22 US pork plants with the numerical scoring system. The data from these audits were compiled by the author. Ninety-five percent of twenty pork plants (19 out of 20) that used electric stunning placed the tongs in the correct location on 99% or more of the pigs. Two plants that used CO<sub>2</sub> rendered 100% of the pigs completely insensible. Out of the 20 electric stunning plants, only one failed to render 100% of the pigs completely insensible. All of the electric stunning plants had either single-file or double-file races and a conveyor restrainer. One plant with group CO<sub>2</sub> stunning had 0% electric goad use. Fourteen plants out of 22 plants (63%) used electric goads on 15% or less of the pigs and 3 (14%) used them on 16 to 25% of the pigs.

The performance of some plants is still poor. The author recently visited two pork plants and one used an electric prod on 100% of the pigs and the other failed to render sows insensible with a captive bolt due to poor gun maintenance. Handling and stunning was poor in several German and Spanish plants. Velarde *et al.* (2000) surveyed two plants with CO<sub>2</sub> stunning where many pigs showed signs of return to sensibility. This was most likely due to overloading of the machine and insufficient exposure time in the gas. In a German plant, Schaffer *et al.* (1997) reported that 96.4% of the pigs were prodded with the electric goad at the entrance of the restrainer.

### Stunning methods

#### Electric stunning

To induce instantaneous insensibility, electrical stunning must induce an epileptic state by passing an electrical current through the pig's brain (Hoenderken, 1978, 1983; Warrington, 1974; Croft, 1952; Lambooij *et al.*, 1996; Gregory, 1998). There are two basic types of electrical stunning. Head only where the tongs are placed across the head, and cardiac arrest where a current is passed through both the head and heart. Head only stunning is reversible and the pig will return to sensibility unless bled quickly. Cardiac arrest stunning will kill most of the pigs by stopping the heart. For pigs, the amperage that is required to induce epilepsy is 1.25 amps (Hoenderken, 1978, 1983). There must also be sufficient voltage to deliver the current. The recommended minimum voltage is 250 volts (Troeger and Woltensdorf, 1989).

To reduce blood splashing (petechial haemorrhages) in the meat, some slaughter plants use high frequency stunning. However, a high electrical frequency of 2000 to 3000 Hz failed to induce instantaneous insensibility (Croft, 1952; Warrington, 1974; Van der Wal, 1978). Fifty cycles, which is the regular mains electrical frequency, was the most effective (Warrington, 1974). Anil and McKinstry (1994) found that 1592 Hz sine wave or 1642 Hz square wave head only stunning at 800 mA induced seizure activity in small pigs. The main disadvantage is that at frequencies above 50 Hz return to sensibility will occur more quickly (Anil and McKinstry, 1994). Due to kicking, high frequency head only stunning is not practical unless it is combined with an additional current to stop the heart. Eight hundred Hz head only stunning in conjunction with a 50 Hz current applied to the body is effective (Lambooij *et al.*, 1996; Berghaus and Troeger, 1998; Wenzlawowicz *et al.*, 1999). This system is available in commercially built equipment.

Most plants in the US apply a single current passed from the head to the body. It is essential to apply sufficient current to induce both cardiac arrest and an epileptic seizure. The author has observed large sows where sufficient current was applied to induce cardiac arrest but insensibility was not induced. In this situation, the sows had natural spontaneous blinking five seconds after stunning which later disappeared due to cardiac arrest (Grandin, 2001a). Raising the amperage to greater than 1.25 amp eliminated blinking in sows. The blink looked like the blink of an unstunned pig and it was not rapid nystagmus.

Electrodes must be placed in the correct position to put the brain in the currents path (Croft, 1952; Warrington, 1974; Anil and McKinstry, 1998). Placing the electrodes too far back on the neck will result in a shorter period of insensibility (Velarde *et al.*, 2000). Grandin (2001a) observed that placing the head electrode of a cardiac arrest stunner too far back on the neck resulted in blinking pigs. Placing the electrode in the hollow behind the ear eliminated the eye reflexes.

Electronic systems are now available to control amperage surges that cause petechial haemorrhages and monitor how well the operator applies the stunning tongs. Gregory (2001) monitored the electrical tracings of stuns to detect problems such as poor initial contact with the animal or interrupted stuns. He concluded that animal welfare problems occurred in about 9% of the stuns. Ross (2002) has developed an electronic microprocessor system that controls waveform, frequency and stun time. This computerized system also records operator errors that would compromise pig welfare such as interrupted stuns and energizing the electrode before it is in full contact with the pig. Unpublished data collected from these computers indicate that stunner operator errors due to fatigue greatly increase after 2 hours. Premature energizing of the electrode will cause squealing. Squealing is correlated with physiological indicators of stress (Warriss *et al.*, 1994). White *et al.* (1995) reported that squealing is associated with discomfort.

Grandin (2001a) has found that problems with return to sensibility after electrical stunning can be easily corrected. The most common causes of problems with return to sensibility were wrong position of the tongs and poor bleeding technique (Grandin, 2001a). Improving the ergonomic design of the head to back cardiac current stunning tongs or the employee's workstation, eliminated problems with return to sensibility.

#### CO<sub>2</sub> stunning

There has been controversy about the humaneness of CO<sub>2</sub> stunning because insensibility is not instantaneous. It takes about 21 seconds for a pig to lose a somatosensory evoked potential (Raj *et al.*, 1997). This is the point where a pig's brain will not respond to a shock on the leg. Gregory *et al.* (1987) found that narcosis began 30 to 39 seconds after the start of immersion. Exposure to CO<sub>2</sub> stimulates breathing frequency and may lead to respiratory distress (Raj and Gregory, 1995). Raj *et al.* (1997) found that stunning pigs in argon resulted in a faster loss of consciousness than CO<sub>2</sub>.

Dutch research indicated that the excitation phase that occurs during CO<sub>2</sub> stunning starts prior to the onset of unconsciousness (Hoenderken, 1983, 1978). This study raised the first questions of potential distress in pigs during the induction of CO<sub>2</sub> anaesthesia. However, research by Forslid (1987) indicated that unconsciousness occurred prior to the onset of the excitation phase and that CO<sub>2</sub> stunning was not stressful. This study, carried out at the Swedish Meat Research Institute, had been on Yorkshire pigs (Anders Forslid, personal communication). In Yorkshire x Landrace crossbred pigs, exposure to CO<sub>2</sub> was less aversive than electrical shocks from an electric goad (Jongman *et al.*, 2000). Dodman (1977) reported that there was great variability on how pigs reacted to CO<sub>2</sub>. Grandin (1988b) observed, in a commercial slaughter plant in the US, that

white crossbred pigs (with Yorkshire breed-type characteristics) had a much milder reaction to CO<sub>2</sub> than black, white-striped crossbred pigs with Hampshire breed-type colouration.

Hampshire-type pigs rode quietly in the gondola until they first contacted the gas and then they reared up and violently attempted to escape. This occurred while they were fully conscious (Grandin, 1988a). Grandin (1994) observed that Danish pigs (which have a very low incidence of the Halothane gene) remained calm when they breathed CO<sub>2</sub>, but that Irish pigs (which have a high incidence of the Halothane gene) became highly agitated within seconds after sniffing the gas. More recent observations by the author in Denmark, of pigs that were free of the Halothane gene indicated that they remained calm after immersion in 90% CO<sub>2</sub> until they collapsed and appeared to lose consciousness. There were no attempts by the pigs to escape from the container.

Experiments with Pietrain x German Landrace pigs indicated that Halothane-positive pigs had a more vigorous reaction to CO<sub>2</sub> than Halothane-negative pigs (Troeger and Woltersdorf, 1991). These pigs had little or no reaction during initial contact with the gas; the reaction started about 20 seconds after the animals contacted the gas. Seventy percent of the Halothane-positive pigs had strong motoric reactions while only 29% of the Halothane-negative pigs reacted in this manner. Troeger and Woltersdorf (1991) expressed concern that reactions in Halothane-positive animals may possibly be of animal welfare concern but concluded that the use of high CO<sub>2</sub> concentrations (80% or greater) reduced the incidence of vigorous reaction.

Human beings also vary in their reaction to CO<sub>2</sub>. People who have panic attacks, which has a strong genetic basis, will react very badly to CO<sub>2</sub>; the gas may induce panic attacks in these people (Griez *et al.*, 1990; Bellodi *et al.*, 1998). Raj and Gregory (1995) found that pigs exposed to CO<sub>2</sub> were more reluctant to re-enter a box to eat apples than pigs exposed to argon. The pig breed used in this experiment was not specified. Research shows that 90% CO<sub>2</sub> works the most effectively (Hartung *et al.*, 2002). Hartung *et al.* (2002) found that in German pigs 80% CO<sub>2</sub> was not sufficient to eliminate all reflexes after a 70-second exposure. They were also concerned about the high catecholamine levels after stunning. Raj and Gregory (1995) reported that no escape attempts occurred at 80 to 90% CO<sub>2</sub> but one out of six piglets attempted to escape at 40 to 50% CO<sub>2</sub> and air. The use of a mixture of CO<sub>2</sub> and argon gas may create an improved gas stunning system for pigs (Raj *et al.*, 1997; Raj, 1999). It is possible that a combination of CO<sub>2</sub> and argon might make CO<sub>2</sub> stunning less stressful for genetic types of pigs that react badly to CO<sub>2</sub>.

One welfare advantage of CO<sub>2</sub> stunning is that CO<sub>2</sub> systems can be designed so that lining pigs up in single-file races can be eliminated. The pigs are moved into the CO<sub>2</sub> chamber in groups of five. Handling pigs in groups makes quiet handling easier. Whereas cattle and sheep are animals that will naturally walk in single file, pigs resist lining up in a single-file race (Grandin, 2000b). Systems in which cattle and sheep are moved through single-file races work extremely well (Grandin, 2000a).

In evaluating CO<sub>2</sub> from a welfare perspective, one should look at the whole system. Eliminating single-file races provides a welfare advantage and the trade-off may be some unpleasantness during anaesthesia induction. However, it is the author's opinion that pigs attempting to escape from the container when they first contact the gas is not acceptable and that genetic factors should be evaluated.

### Bleeding methods

Poor bleeding practices were often the cause of pigs returning to sensibility (Grandin, 2001a). When reversible stunning methods are used, pigs must be bled promptly to prevent return to sensibility

(Wotton and Gregory, 1986). When a pig is bled by sticking in the chest region, an average of 18 seconds is required for the brain to stop responding to a visual stimulus (Wotton and Gregory, 1986). If bleeding is poor and only one carotid artery is cut, it takes much longer to lose the response to a visual stimulus (Wotton and Gregory, 1984). This study illustrates the importance of effective bleeding.

When head only reversible electric stunning is used, Hoenderken (1978) recommends bleeding pigs within 30 seconds to prevent return to sensibility. However, Blackmore and Newhook (1981) recommend that they be bled within 15 seconds. Even when non-reversible methods are used, the author has observed that a few pigs may show signs of returning to sensibility. Stunning to bleed interval time is less critical when non-reversible stunning methods are used but effective bleeding is essential to ensure that pigs showing signs of sensibility never enter the scalding. Grandin (2001a) found that improving bleeding so that the diameter of the initial blood stream was large prevented signs of return to sensibility after bleeding.

### How to determine insensibility in the plant

A slaughter plant is not a laboratory with controlled conditions; therefore it is the author's opinion that the standards for determining insensibility must be conservative. Judging the depth of surgical anaesthesia is not a precise science. In the human literature, Stanski *et al.* (1994) cited 33 journal articles where people had awareness or remembered events during surgery. There appears to be no distinct dividing line between consciousness and unconsciousness. Martoft *et al.* (2001) reported that a pig's brain reacts to an auditory stimulus in a similar manner in both sedated and aware pigs. More research is needed to correlate easily observed signs of return to sensibility with depth of anaesthesia in pigs stunned with electricity or CO<sub>2</sub>.

Research by Anil and McKinstry (1994) showed that in pigs stunned with reversible head only electric stunning, return to sensibility occurred in the following order: 1) rhythmic breathing, 2) corneal eye reflex, 3) respond to prick on the nose with a needle, 4) righting reflex to get up, 5) fully sensible. Holst (2001) found that return to sensibility after CO<sub>2</sub> stunning occurred in the following order: 1) corneal reflex, 2) rhythmic breathing, 3) nystagmus (vibrating eye), 4) spontaneous natural eye blinking without touching the eye and 5) righting reflexes to get up.

At what point in this hierarchy of return to sensibility is the pig fully sensible and able to feel pain and other unpleasant sensations? Gregory (1998) states that a corneal reflex which is evoked by touching the eye can occur in both conscious and unconscious animals. If this reflex is absent one can assume that the animal is in a profound state of brain dysfunction and unconsciousness (Gregory, 1998).

Spontaneous blinking like a live animal would do in the lairage is at a higher level on the hierarchy of return to sensibility than a corneal reflex evoked by touch. It is likely that at this point the animal is sensible. The author has observed electrically stunned pigs getting up and walking around within 10 seconds after the appearance of spontaneous natural blinking.

When pigs are either hanging on the slaughter line or lying on a bleed table, the most common mistake is to misinterpret leg kicking as a sign of sensibility. In electrically stunned pigs it is normal to have kicking. The presence of the classic tonic and clonic spasms is a sign of an effective electrical stun that has induced an epileptic seizure (Croft, 1952). The rigid tonic phase is followed by kicking (clonic phase). Gregory (1998) states that a completely relaxed jaw is a good indicator of brain dysfunction and unequivocal unconsciousness. When this occurs the tongue will be flaccid and extended. The one reflexive movement that is difficult to abolish is gasping, it is a sign of a dying brain (Gregory, 1998).



The righting reflex looks different when a pig is hanging on the rail. A properly stunned pig regardless of stunning method will hang on the rail with a straight back and flaccid head (Grandin, 2001a). When a righting reflex occurs, the neck and lower back arch and stiffen as the animal attempts to lift up its head. Some fully sensible pigs will curl their heads forward towards their forelegs.

The author has observed that misinterpretation of eye reflexes in electrically stunned pigs is a problem especially when untrained people poke at the eye. Eyelids that are stuck closed with mucous can suddenly open and look like a reflex (Grandin, 2001a). Under commercial conditions, both Grandin (2001a) and Holst (2001) agree that spontaneous natural eye blinking without touching the eye must be absent at all times after stunning. It is an easy sign to observe and it is less likely to be misinterpreted (Grandin, 2001a; Holst, 2001). Natural spontaneous blinking is never acceptable but a maximum of 5% of CO<sub>2</sub> stunned pigs can have a corneal reflex evoked by touch (Holst, 2001). Nystagmus (vibrating eye) must not be confused with natural blinking and this will occur in some pigs stunned correctly with electricity.

### Handling during truck loading, unloading and pre-slaughter

To have good pig welfare during transport and slaughter, pigs must be handled by well-trained people. When the welfare of pigs is being assessed during handling, one must first determine if there is a people problem, animal problem or a facility problem. Welfare is poor if pigs are piled up and constantly squealing. The author has observed that facility problems can be divided into three categories: 1) minor problems that can be easily fixed, 2) a major design fault or 3) an overloaded facility that does not have sufficient capacity for the plant's line speed or an overloaded truck.

Both at the slaughter plant and at the farm loading trucks, people must understand the basic behavioural principles of animal handling such as flight zone and point of balance (Grandin, 1987). Calm pigs are easier to move and sort than excited, agitated pigs. Another principle is to move small groups of animals and to fill the forcing pen that leads up to the single file race half full (Grandin, 2000b). Animals will also move more easily up a single-file race or truck-loading ramp if they walk without stopping through the forcing pen. Pigs left standing in a forcing pen are more likely to turn around.

Electric goads should be replaced as much as possible with other non-electric driving aids. Pigs moved with electric goads have a higher heart rate than pigs moved with a panel (Brundige *et al.*, 1998). A study by Benjamin *et al.* (2001) indicated that prodding pigs multiple times with electric goads results in a significant increase in the number of stressed pigs that became non-ambulatory. Electric goads also increased body temperature and blood lactate (Brundige *et al.*, 1998). Some effective non-electric driving aids are panels, plastic paddle sticks and a large flag made of lightweight plasticized cloth (Grandin, 2000b). Small groups of calm pigs can be easily moved with these driving aids.

### Distractions that hinder pig movement

Pigs are very sensitive to distractions such as shadows, reflections and small moving objects. These small distractions can impede pig movement through single-file races, alleys, truck loading ramps and into conveyor restrainers or CO<sub>2</sub> chambers (Grandin, 1996, 1998). Good welfare and a reduction of electric goad use are impossible if pigs constantly back up or turn back. Removing distractions that cause pigs to balk or back up makes it possible to greatly reduce electric prod use (Grandin, 1996).

Both research and practical experience show that pigs have a tendency to move from a dark place to a brighter place (Van Putten and Elshof, 1978; Grandin, 1982, 1996; Tanida *et al.*, 1996). Installing a light at the entrance of a restrainer can improve pig movement and reduce electric prod usage (Grandin, 1996). Animals will also baulk and back up if air draughts are blowing towards them as they approach a race or restrainer entrance. A calm pig will look right at the distraction that attracts its attention (Grandin, 2000b). Quiet handling of pigs will be impossible until all the distractions are found and eliminated. Another common distraction is seeing people or moving machinery up ahead. Solid sides on races and shields can help block these distractions. Pigs will also baulk at sparkling reflections on a wet floor or shiny metal. Sometimes all that is required is to move a light on the ceiling to eliminate a reflection (Grandin, 1996, 2000b). Schaffer *et al.* (1997) reported that in one plant pigs refused to enter a restrainer and 96.4% had to be shocked with an electric prod. It is the author's opinion that eliminating a few small distractions may improve pig movement in this plant. People need to get down to the pig's level and see what the pig is seeing. A reflection that the pig sees may not be visible to someone standing. Another problem is seeing the visual cliff effect under a conveyor restrainer that is elevated off the floor. Animals can perceive depth (Lemman and Patterson, 1964). Installation of a false floor under a restrainer can facilitate animal entry (Grandin, 1996, 2001b).

### Reduce noise

Pigs will remain calmer if there is less noise. Spensley (1995) reported that novel noises ranging from 80 to 90 dB increased the heart rate of pigs. Intermittent noises were more disturbing to pigs than continuous noises (Talling *et al.*, 1998). Air exhausts that hiss should be muffled and clanging metal should be silenced (Grandin, 1996). Geverink *et al.* (1998a) studied the response of pigs to recorded sounds of machinery or white noise. Pigs exposed to the loud 85 dB sound spent more time close to group mates.

When new plants are built, consideration should be given to reduce noise. After visiting many plants, the author has observed that lairage areas with high ceilings and pre-cast concrete walls have more echoes and noise than plants built from metal clad foam core insulation panels (Grandin, 2000b). The author visited a plant with pre-cast concrete walls and the sound level was 88 dB in the lairage and 93 dB at the restrainer. The pigs were quiet and all the equipment was running.

### Facility design at the slaughter plant

It is beyond the scope of this paper to provide a complete review of the design of facilities. Many different types of facilities can work with an acceptable level of welfare if people are trained and the distractions that cause baulking or backing up are removed. Restaurant audit data indicated that making many small changes in existing facilities to eliminate distractions and slick floors improved animal movement (Grandin, 2000b).

Information on the layout and design of races and lairages for slaughter plants can be found in Grandin (1990, 2000b; Barton-Gade *et al.*, 1993). The use of long narrow lairage pens is recommended (Grandin, 1980, 2000b). Long narrow pens increase the fence line length in relation to the floor area and may help reduce fighting. Pigs prefer to lie along the fence (Stricklin *et al.*, 1979). The author has observed that slick floors are a common cause of animals falling and other welfare problems during handling. Non-slip flooring is essential.

### Races, forcing pen and restrainer design

Adequate levels of welfare can be obtained in single-file race systems if they are designed correctly and all distractions are removed. Reducing electric prod use to 15% to 18% of the pigs can be easily accomplished (Grandin, 1998). Solid sides are recommended on



paces and forcing pens (Grandin, 1982). A race must be long enough to ensure a continuous flow but not so long as to cause stress in pigs waiting in line (Grandin, 2000b). Line speed determines how long a race should be. Hartung *et al.* (1997) found that pigs were less stressed in a short 3.5-m race compared to an 11-m race. German plants run at slower speeds than US plants. The author has observed that a short 3.5-m race in an 800-pig per-hour plant causes stress because keeping up with the slaughter line would be difficult. Therefore a race length that is appropriate for a small plant may work poorly in a big plant. Races and forcing pens built in new plants should be level. A pig's heart rate increases as the angle of a ramp increases (Van Putten and Eshof, 1978). Pigs move most easily on a level surface. In plants processing 240 or fewer pigs per hour, electric stunning of groups of pigs on the floor was less stressful than a single-file race (Warriss *et al.*, 1994). The author has observed that in larger plants, floor stunning with tongs often gets rough and careless.

A single-file race must never be bent sharply where it joins the forcing pen. The pigs will refuse to enter because they see no place to go. A paper by Weeding *et al.* (1993) shows a poorly designed single-file race and pigs handled in this system had increased stress. Pigs will jam in a funnel-shaped crowd pen leading up to a single-file race. A pig race must have an abrupt entrance. Crowd pen design for pigs is discussed in further detail by Hoenderken (1976) and Grandin (1982, 2000b).

The design of conveyor restrainers will also affect welfare. The author has observed that heavily muscled pigs are not well supported in traditional conveyor restrainers. The new centre conveyor restrainers that a pig straddles support heavy muscle pigs better. The use of these restrainers is discussed elsewhere (Giger *et al.*, 1977; Grandin, 1988, 2000b, 2003). These systems are now commercially available. Pigs should enter the restrainer easily. If they refuse, distractions should be located and removed. A reasonable level of performance is when 85% of the pigs enter without the need for an electrical goad (Grandin, 1998).

### Pig factors that affect handling and transport

Many handling problems are caused by pigs that are very difficult to move. At the slaughter plant the author has observed groups of excitable pigs that were almost impossible to handle quietly. Both genetics and previous experience will affect the ease of handling of pigs. Piglets that have never walked on concrete may balk and be difficult to move. The author's experience on farms has indicated that moving the animals will be easier if they are given an opportunity to explore the new floor surface prior to being driven over it.

British researchers have reported that pigs from certain farms are more difficult to drive (Hunter *et al.*, 1994). Geverink *et al.* (1998c) reports that pigs that have been walked in the aisle during finishing will be easier to drive. Moving pigs out of the finishing pens a month prior to slaughter also improved their willingness to move (Abbott *et al.*, 1997).

Pigs from certain lean genetic lines may be more excitable and difficult to drive (Grandin, 1987). Shea-Moore (1998) found that high-lean pigs were more fearful and explored an open arena less than a fatter line of pigs. Lean-line pigs also got into more fights after mixing (Buss and Shea-Moore, 1999). More time was required to move lean-line pigs down an alley compared to a fatter line of pigs. Work with producers by the author has shown that excitability can be reduced and the pigs will be easier to drive if the producers walk through the pens every day (Grandin, 2000b). This is especially important for pigs from excitable genetic lines. Grandin *et al.* (1984) found that people walking in the pens or allowing pigs to walk in the aisles produced pigs that were more willing to walk through a chute (race). The author recommends that the producer should walk

through both grower and finishing pens every day to teach the pigs to quietly get up and flow around him. Pigs differentiate between a person in the aisle and a person in their pens.

Another factor which may increase both handling and potential welfare problems is feeding pigs the repartitioning agent ractopamine to make pigs leaner. Marchant-Forde *et al.* (2002) reported that pigs fed 10 ppm had higher heart rates during handling and higher epinephrine levels. The authors conclude that "the results show that ractopamine does affect the behaviour and physiology of finishing pigs and may make them more difficult to handle and more susceptible to handling and transport stress".

One of the most important factors which determines if a pig is fit for transport is the condition of the pig when loaded onto the truck. Cull sows should be marketed when they are still fit for travel. Sows and pigs that are unable to walk should be euthanized on the farm. Stressor pigs which have temporarily become non-ambulatory must be allowed to recover before they are put on a truck. A combination of genetic selection for leanness and poor management has resulted in increased sow mortality (Koketsu, 2000). Interviews with producers by the author indicated that leg problems are a large contributor to these sow losses and transporting lame sows may cause welfare problems. Producers and breeders need to select sound animals with good feet and legs. Recently the author has observed that some slaughter weight pigs are lame and have poor conformation of the feet and legs.

The presence of the stress gene will increase death losses during transport. Murray and Johnson (1998) found that 9.2% of the pigs that were homozygous positive for the stress gene died during transport. Death loss percentages were 0.27% in heterozygous stress gene carriers and 0.05% in pigs that were stress gene-free. Fortunately many producers are now selecting pigs that are stress gene-free to improve meat quality. A survey of pigs arriving dead on arrival at the slaughter plant indicated that deaths decreased from 0.27% to 0.1% when the stress gene was removed (Holtcamp, 2000).

### Loading and unloading equipment

Non-slip flooring is essential on loading ramps and alley floors. A good finish is to print the pattern of expanded metal into wet concrete. Ideally the ramp angle should not exceed 20 degrees for a non-adjustable ramp and 25 degrees for an adjustable ramp (Grandin, 1987). A pig's heart rate will increase as the angle of a loading ramp increases (Van Patten and Elshof, 1978). Mayes (1978) studied a pig's stride width and found that cleats on ramps must be spaced to fit the normal walking stride of an animal. For 120-kg slaughter weight pigs, the cleats should be on 20-cm centres (2.5 cm x 2.5 cm cleats). Missing cleats must be immediately replaced to prevent leg injuries. Stairsteps work well on concrete ramps. For slaughter weight pigs, the ramp should have a 6.5-cm rise and a 25-cm long tread (Grandin, 1987).

The author has observed that small piglets can get dew claw injuries when they go down a ramp designed for slaughter weight pigs. The animals slip and damage their dew claws. To prevent injuries to young piglets small closely spaced cleats are required. Further information on the design of loading ramps can be found in Grandin (1987, 1990, 2000b).

### Truck stocking density

Overloading of trucks is a major cause of increased stress and death losses. Warriss (1998) reported that overloading of trucks results in clear evidence of physical stress when 100-kg pigs are stocked at 322 kg/m<sup>2</sup>. At this stocking rate there may not be enough room for all the pigs to lie down (Warriss, 1998). Appropriate stocking densities may vary depending upon the length of the journey and the temperature.

There needs to be a differentiation between long and short trips. Both Guise *et al.* (1998) and Gade and Christenson (1998) found that 100-kg pigs remain standing during short trips of 1.5 to 3 hours. Gade and Christensen (1998) found that during moderate weather in Denmark providing additional space for short trips resulted in no improvements in skin damage or stress indicators in the blood such as creatine phosphokinase, lactate and cortisol. On longer trips and during very hot weather pigs will need more space to lie down without being on top of each other.

### Stressfulness of transport

Vibration in a vehicle is uncomfortable to pigs and they will vomit during transport (Bradshaw *et al.*, 1996). Vibration may be more aversive than noise (Stephens *et al.*, 1985). Perremans *et al.* (2001) found that low frequency vibrations of 2 to 4 Hz were more stressful than 8 to 18 Hz. At 2 to 4 Hz pigs spent 10 times less time lying down. Vibration stress may be reduced as more and more people purchase vehicles with air suspension.

There is evidence that travel in a vehicle is more stressful than just being loaded onto a stationary truck for the same amount of time. After a 25-minute ride or a stationary wait in a truck, Geverink *et al.* (1998) reported that after unloading the pigs that were actually transported were less active and spent less time exploring their environment. Salivary cortisol was also significantly higher in the transported group (Geverink *et al.*, 1998).

Further research is needed to determine if uncomfortable vibration is the reason why pigs remain standing on short journeys. It is possible that they lie down when they become too fatigued to stand any longer. This question needs to be answered to determine if pigs need enough room to lie down on short journeys.

### Recovery from transport stress and lairage

Several studies have been conducted to determine how long it takes pigs to recover from transport stress after they are unloaded at a slaughter plant. In one experiment 80- to 100-kg Large White pigs were transported for 16 to 24 hours and then brought to a lairage with feed and water. After 2 to 6 hours of lairage, the physiological parameters returned to normal (Brown *et al.*, 1999; Warriss *et al.*, 1992).

For both meat quality and welfare reasons, pigs should be rested for 2 hours before slaughter (Milligan *et al.*, 1998). The author's observations of thousands of pigs indicate that pigs moved to the stunning area immediately after unloading were much harder to handle and more electric goad use was required to move them than pigs that were rested for a minimum of one hour. Perez *et al.* (2002) found that either no lairage time or an excessively long lairage time compromised both welfare and pork quality. Leheska *et al.* (2002) reported that long transport times reduced PSE (pale, soft and exudative) and improved pork quality compared to short transport times of 30 minutes. They also found that fasting for 48 hours improved pork quality. The author is concerned, however, about the welfare implications of a 48-hour fast.

Many plants shower pigs in the lairage to reduce PSE. Sometimes pigs are showered during very cold weather which is probably detrimental to their welfare. Knowles *et al.* (1998) reports that pigs should not be showered continuously when the temperature is below 5 °C and showering should stop when pigs shiver.

### Mixing and fighting in pigs

In large slaughter plants it is often difficult not to mix pigs. The author's observations at many slaughter plants indicate that small groups of mixed pigs fight much more than large groups of 200. In the USA large groups of 150 to 200 pigs are mixed in large lairage

pens and most pigs lie down and go to sleep. Problems caused by mixing pigs will probably decline as the industry moves to wean to finish units where several hundred pigs are fattened in a single room. When large groups of pigs are mixed there is less fighting compared to mixing small groups.

Brown *et al.* (1999) found that pigs from one farm fought more than pigs from another farm. If pigs do fight the stress of mixing and being driven down an alley is greater than either stressor singly (Geverink *et al.*, 1998b). From a welfare standpoint, it is the author's opinion that monitoring skin damage is a good way to monitor welfare problems from fighting. This may be a better approach than specifying that pigs should never be mixed.

### Heat and cold stress losses

Warriss and Brown (1994) reported that death losses in 100-kg pigs during transport increased from 0.04% to 0.16% when the temperature increased from 5 °C to about 22 °C. In the USA the extremes of temperature will greatly exceed 22 °C and winter temperatures are very cold. Summertime temperatures often reach 38 °C and winters are much colder than in England. US Department of Agriculture figures collected by meat inspectors indicated that in the year 2000, 0.30% of the market weight pigs arrived at the plant dead. Unpublished data from a large integrated swine operation indicated that death losses in heavy 120-kg pigs may rise to 0.27% to 0.3% when the temperature is 35 °C. When the temperature is low the losses are 0.1% to 0.2%. During the winter severe frostbite may occur in pigs. This is very detrimental to welfare. Bedding the truck with deep straw helps to reduce frostbite.

### Monitoring welfare

The welfare of pigs during transport can be easily monitored with numerical scoring to prevent abuse. Data on death losses, frostbite, severe skin damage from fighting and hard to handle pigs should be tabulated by pig producers and truck drivers. From twenty years of experience, the author has learned that holding people financially accountable is one of the best ways to improve both welfare and pork quality. At two large integrated pig farms the author has observed that incentive pay for truck drivers and producers will reduce death losses.

Handling during loading of pigs can be scored with a similar scoring system. Drivers could be scored on death losses, the percentage of pigs that fall down during driving, and electric goad use. In conclusion, holding people accountable for losses and the use of numerical scoring systems will help managers to maintain high standards.

### References

- Abbott, T.A.; Hunter, E.J.; Guise, J.H.; Penny, R.H.C. (1997) The effects of experience of handling on pig's willingness to move. *Applied Animal Behavior Science* 54, 371–375.
- Anil, A.M.; McKinstry, J.L. (1994) The effectiveness of high frequency electrical stunning in pigs. *Meat Science* 31, 481–491.
- Anil, M.H.; McKinstry, J.L. (1998) Variations in electrical stunning tong placements and relative consequences in slaughter pigs. *Veterinary Journal* 155, 85–90.
- Barton-Gade, P.; Blaabjerg, L.; Christensen, L. (1993) A new lairage system for slaughter pigs. *Meat Focus International* 2, 115–118.
- Bellodi, L.; Giampaolo, P.; Caldriola, D.; Arancro, C.; Bertani, A.; DiBelle, D. (1998) CO<sub>2</sub> induced panic attacks: A twin study. *American Journal of Psychiatry* 155, 1184–1188.
- Benjamin, M.E.; Gonyou, H.W.; Ivers, D.L.; Richardson, L.F.; Jones, D.J.; Wagner, J.R.; Seneriz, R.; Anderson, D.B. (2001) Effect of handling method on the incidence of stress response in market swine in a model system. *Journal of Animal Science* 79, 279 (Suppl. 1) (Abstract).
- Berghaus, A.; Troeger, K. (1998) Electrical stunning of pig's minimum current flow time required to induce epilepsy at various

- frequencies. *International Congress of Meat Science and Technology* **44**, 1070–1073.
- Blackmore, D.K.; Newhook, J.C. (1981) Insensibility during slaughter of pigs in comparison to other domestic stock. *New Zealand Veterinary Journal* **29**, 219–222.
- Bradshaw, R.H.; Parrott, R.F.; Forling, M.L.; Good, J.A.; Lloyd, D.M.; Rodway, R.G.; Broom, D.M. (1996) Stress and travel sickness in pig: Effects of road transport on plasma concentrations of cortisol, beta endorphin, lysine and vasopressin. *Journal of Animal Science* **63**, 507–519.
- Brown, S.N.; Knowles, T.G.; Edwards, J.E.; Warriss, P.D. (1999). Behavioral and physiological responses of pigs to being transported for up to 24 hours followed by six hours recovery in lairage. *Veterinary Record* **145**, 421–426.
- Brundige, L.; Okeas, T.; Doumit, M.; Zanella, A.J. (1998) Loading techniques and their effect on behavior and physiological responses of market pigs. *Journal of Animal Science* **76** (Suppl. 1) 99 (Abstract).
- Buss, C.S.; Shea-Moore, M.M. (1999) Behavioral and physiological responses to transportation stress. *Journal of Animal Science* **77** (Suppl. 1) 147 (Abstract).
- Croft, P.S. (1952) Problems with electrical stunning. *Veterinary Record* **64**, 255–258.
- Dodman, N.H. (1977) Observations on the use of the Wernberg dip-lift carbon dioxide apparatus for pre-slaughter anesthesia pigs. *British Veterinary Journal* **133**, 71–80.
- Forslid, A. (1987) Transient neocortical, hippocampal and amygdaloid EEG silence induced by one minute inhalation of high concentration CO<sub>2</sub> in the swine. *Acta Physiologica Scandinavica* **130**, 1–10.
- Gade, P.B.; Christensen, L. (1998) Effect of different stocking densities during transport on welfare and meat quality in Danish slaughter pigs. *Meat Science* **48**, 237–247.
- Geverink, N.A.; Buhmann, A.; van de Burgwal, J.A.; Lambooi, E.; Blokhuis, H.J.; Wiegant, V.M. (1998a) Responses of pigs to lairage sounds. *Physiology and Behavior* **15**, 667–673.
- Geverink, N.A.; Bradshaw, R.H.; Lambooi, E.; Wiegant, V.M.; Broom, D.M. (1998b) Effects of simulated lairage conditions on the physiology and behavior of pigs. *Veterinary Record* **143**, 241–244.
- Geverink, N.A.; Kappers, A.; Van de Burgwal, E.; Lambooi, E.; Blokhuis, J.H.; Wiegant, V.M. (1998c) Effects of regular moving and handling on the behavioral and physiological responses of pigs to pre-slaughter treatment and consequences for meat quality. *Journal of Animal Science* **76**, 2080–2085.
- Giger, W.; Prince, R.P.; Westervelt, R.G.; Kinsman, D.M. (1977) Equipment for low stress animal slaughter. *Transactions of the American Society of Agricultural Engineers* **20**, 571–578.
- Grandin, T. (1980) Livestock behavior as related to handling facility design. *International Journal of the Study of Animal Problems* **1**, 33–52.
- Grandin, T. (1982) Pig behavior studies applied to slaughter plant design. *Applied Animal Ethology* **9**, 141–151.
- Grandin, T. (1987) Animal handling. *Veterinary Clinics of North America Food Animal Practice* **3**, 323–338.
- Grandin, T. (1988) Double rail restrainer for livestock handling. *Journal of Agricultural Engineering Research* **41**, 327–338.
- Grandin, T. (1988) Possible genetic effect on pig's reaction to CO<sub>2</sub> stunning. *Proceedings International Congress of Meat Science and Technology, Brisbane, Australia* **34**, 96–97.
- Grandin, T. (1990). Design of loading and holding pens. *Applied Animal Behavior Science* **28**, 187–201.
- Grandin, T. (1994) Euthanasia and slaughter of livestock. *Journal of the American Veterinary Medical Association* **204**, 1354–1360.
- Grandin, T. (1996) Factors that impede animal movement at slaughter plants. *Journal of American Veterinary Medical Association* **209**, 757–759.
- Grandin, T. (1998) Objective scoring on animal handling and stunning practices in slaughter plants. *Journal of the American Veterinary Medical Association* **212**, 36–39.
- Grandin, T. (2000a) Effect of animal welfare audits of slaughter plants by a major fast food company on cattle handling and stunning practices. *Journal of the American Veterinary Medical Association* **216**, 848–851.
- Grandin, T. (2000b). Handling and welfare of livestock in slaughter plants. In: *Livestock Handling and Transport, 2nd edition* [edited by Grandin, T.] CABI Publishing, Wallingford, Oxford, UK; pp. 409–439.
- Grandin, T. (2001a) Solving return to sensibility problems after electrical stunning in commercial pork slaughter plants. *Journal of the American Veterinary Medical Association* **219**, 608–611.
- Grandin, T. (2001b). Cattle vocalizations are associated with handling and equipment problems in beef slaughter plants. *Applied Animal Behaviour Science* **71**, 191–201.
- Grandin, T. (2003) Transferring results of behavioral research to industry to improve animal welfare on the farm, ranch and the slaughter plant. *Applied Animal Behaviour Science* **81**, 215–228.
- Grandin, T.; Curtis, S.E.; Widowski, T. (1984) Rearing environment affects pig's time to walk through test chute. *Journal of Animal Science* (Suppl. 1) **61**, 88 (Abstract).
- Gregory, N.G. (1998) *Animal welfare and meat science*. CABI Publishing, Wallingford, Oxford, UK.
- Gregory, N.G. (2001) Profiles of currents during electrical stunning. *Australian Veterinary Journal* **79**, 844–845.
- Gregory, N.G.; Moss, B.; Leeson, R. (1987) An assessment of carbon dioxide stunning in pigs. *Veterinary Record* **121**, 517–518.
- Griez, E.; Zandbergen, J.; Pols, J. (1990) Response to 35% CO<sub>2</sub> as a marker of panic and severe anxiety *American Journal of Psychiatry* **147**, 796–797.
- Guise, H.J.; Riches, H.L.; Hunter, B.J.; Jones, T.A.; Warriss, P.D.; Kettlewell, P.J. (1998) The effect of stocking density on transit on carcass quality and welfare of slaughter pigs. *Meat Science* **50**, 439–446.
- Hartung, J.; Nowak, B.; Waldmann, K.H.; Ellerbrock, S. (2002) CO<sub>2</sub> stunning of slaughter pigs: Effects on EEG, catecholamines and clinical reflexes. *Deutsche Tierärztliche Wochenschrift* **109**, 135–139.
- Hartung, V.J.; Floss, M.; Marahrens, M.; Nowak, B.; Fedlhusen, F. (1997) Stress response of slaughter pigs in two different access systems to electrical stunning. *Deutsche Tierärztliche Wochenschrift* **104**, (2) 66–68.
- Hoenderken, R. (1976) Improved system for guiding pigs for slaughter to the restrainer. *Fleischwirtschaft* **56**, (6) 838–839.
- Hoenderken, R. (1978) *Electrical stunning of pigs for slaughter*. Ph.D. dissertation, University of Utrecht, The Netherlands.
- Hoenderken, R. (1983) Electrical and carbon dioxide stunning of pigs for slaughter. In: *Stunning of animals for slaughter* [edited by Eikelenboom, G.], Martinus Nijhoff Publishers, Boston, Massachusetts, USA; pp. 59–63.
- Holst, S. (2001) CO<sub>2</sub> stunning of pigs for slaughter. Practical guidelines for good animal welfare. In: *47th International Congress of Meat Science and Technology, Krakow, Poland* **1**, 48–54.
- Holtcamp, A. (2000) Gut edema: Clinical signs, diagnosis and control. In: *American Association of Swine Practitioners Proceedings*, pp. 337–339.
- Hunter, E.J.; Weeding, C.M.; Guise, H.J.; Abbott, T.A.; Penny, R.H. (1994) Pig welfare and carcass quality: A comparison of the influence of slaughter handling systems in two abattoirs. *Veterinary Record* **135**, 423–425.
- Jongman, E.C.; Barnett, J.L.; Hemsworth, P.H. (2000) The aversiveness of carbon dioxide stunning in pigs and a comparison of CO<sub>2</sub> rate vs. the V restrainer. *Applied Animal Behavior Science* **67**, 67–76.
- Knowles, T.G.; Brown, S.N.; Edwards, J.E.; Warriss, P.D. (1998) Ambient temperature below which pigs should not be continuously showered in lairage. *Veterinary Record* **143**, 576–578.
- Koketsu, Y. (2000) Factors associated with increased sow mortality in North America. In: *Proceedings American Association of Swine Practitioners, March 11–14, 2000*. Indianapolis, Minnesota, USA; pp. 419–420.
- Lambooi, B.; Merkus, G.S.M.; Voorst, N.V.; Pieterse, C. (1996) Effect of low voltage with a high frequency electrical stunning on unconsciousness in slaughter pigs. *Fleischwirtschaft* **76**, 1327–1328.
- Leheska, J.M.; Wulf, D.M.; Maddock, R.J. (2002) Effects of fasting and transportation on pork quality development and extent of postmortem metabolism. *Journal of Animal Science* **80**, 3194–3203.



- Lemman, W.B.; Patterson, G.H. (1964) Depth perception in sheep: Effects of interrupting the mother-neonate bond. *Science* **145**, 835–836.
- Marchant-Forde, J.N.; Lay, D.C.; Richert, B.T.; Pajor, E.A. (2002) The effect of ractopamine on the behavior and physiology of finishing pigs. *Journal of Animal Science* **80**, 82 (Suppl. 1) (Abstract).
- Martoft, L. (2001) *Neurophysiological effects of high concentration CO<sub>2</sub> inhalation in swine*. Ph.D. thesis, Royal Veterinary and Agricultural University, Frederiksberg, Denmark.
- Mayes, H.F. (1978) Design criteria for livestock loading chutes. *American Society of Agricultural Engineers Paper* **78**, 6014. St. Joseph, Missouri, USA.
- Milligan, S.D.; Ramsey, C.B.; Miller, M.F.; Kaster, C.S.; Thompson, L.D. (1998) Resting pigs and hot fat trimming and accelerated chilling of carcasses to improve pork quality. *Journal of Animal Science* **76**, 74–86.
- Murray, A.C.; Johnson, C.P. (1998) Influence of the halothane gene on muscle quality and preslaughter death in western Canadian pigs. *Canadian Journal of Animal Science* **78**, 543–548.
- Perez, M.P.; Palacir, J.; Santolaria, M.P.; delAcena, M.C.; Chacon, G.; Verde, M.T.; Calvo, J.H.; Zaragoza, M.P.; Gascon, M.; Garcia-Belenguer, S. (2002) Influence of lairage time on some welfare and meat quality parameters in pigs. *Veterinary Record* **33**, 239–250.
- Perremans, S.; Randall, J.M.; Rombouts, G.; Decuyper, E.; Geers, R. (2001) Effect of whole body vibration in the vertical axis on cortisol and adrenocorticotrophic hormone levels in piglets. *Journal of Animal Science* **79**, 975–981.
- Raj, A.B. (1999) Behavior of pigs exposed to mixture of gases and the time required to stun and kill them: Welfare implications. *Veterinary Record* **144**, 165–168.
- Raj, A.M.; Gregory, N.G. (1995) Welfare implications of gas stunning of pigs. Determination of aversion to the initial inhalation of carbon dioxide or argon. *Animal Welfare* **4**, 273–280.
- Raj, A.B.; Johnson, S.P.; Wotton, S.B.; McKinstry, J.L. (1997) Welfare implications of gas stunning of pigs. The time of loss to somatosensory evoked potentials and spontaneous electrocorticograms of pigs during exposure to gases. *Veterinary Record* **153**, 329–339.
- Ross, M.H. (2002) *Animal stunning system*. U.S. Patent 6, 471, 576, B1, 20 October, 2002.
- Schaffer, D.; von Borrell, E.; Laube, R.B. (1997) Observations on abattoir personnel on the use of prodding sticks on slaughter pigs in the entrance area of the restrainer. *Deutsche Tierärztliche Wochenschrift* **104**, 479–487.
- Shea-Moore, M. (1998) The effect of genotype on behavior in segregated early weaned pigs in an open field. *Journal of Animal Science* **76** (Suppl. 1), 100 (Abstract).
- Spensley, J.C.; Wathes, C.M.; Waron, N.K.; Lines, J.A. (1995) Behavioral and physiological responses of piglets to naturally occurring sounds. *Applied Animal Behaviour Science* **44**, 277.
- Stanski, D.R. (1994) Monitoring depth of anesthesia. In: *Anesthesia, 4th edition* [edited by Miller, R.] Churchill Livingstone, New York, USA; pp. 1127–1159.
- Stephens, D.B.; Bailey, K.J.; Sharman, D.F.; Ingram, D.L. (1985) An analysis of some behavioral effects of the vibration and noise components of transport pigs. *Quarterly Journal of Experimental Physiology* **70**, 211–217.
- Stricklin, W.R.; Graves, H.B.; Wilson, L.L. (1979) Some theoretical and observed relationships of fixed and portable spacing behavior in animals. *Applied Animal Ethology* **5**, 201–214.
- Talling, J.C.; Waran, N.K.; Wathes, C.M.; Lines, J.A. (1998) Sound avoidance by domestic pigs depends on characteristics of the signal. *Applied Animal Behaviour Science* **58**, 255–266.
- Tanida, H.; Miura, A.; Tanaka, T.; Yoshimoto, T. (1996) Behavioral responses of piglets to darkness and shadows. *Applied Animal Behaviour Science* **49**, 173–183.
- Troeger, K.; Woltersdorf, W. (1989) Measuring stress in pigs during slaughter. *Fleischwirtschaft* **69**, (3) 373–376.
- Troeger, K.; Woltersdorf, W. (1991) Gas anaesthesia of slaughter pigs. *Fleischwirtschaft International* **4**, 43–49.
- Van der Wal, P.G. (1978) Chemical and physiological aspects of pig stunning in relation to meat quality: a review. *Meat Science* **2**, 19–30.
- Van Putten, G.; Elshoff, G. (1978) Observations on the effect of transport on the well being and lean quality of slaughter pigs. *Animal Regulation Studies* **1**, 247–271.
- Velarde, A.; Gispert, M.; Fautitano, L.; Manteca, X.; Diestre, A. (2000) Survey of the effectiveness of stunning procedures used in Spanish abattoirs. *Veterinary Record* **146**, 65–68.
- Warrington, P.D. (1974) Electrical stunning: A review of literature. *Veterinary Bulletin* **44**, 617–633.
- Warriss, P.D. (1998) Choosing appropriate space allowances for slaughter pigs transported by road: A review. *Veterinary Record* **142**, 449–454.
- Warriss, P.D., and Brown, S.N. (1994). A survey of mortality in slaughter pigs during transport and lairage. *Veterinary Record* **134**, 513–515.
- Warriss, P.D.; Brown, S.N.; Adams, S.J.M. (1994) Relationship between subjective and objective assessment of stress at slaughter and meat quality in pigs. *Meat Science* **38**, 329–340.
- Warriss, P.D.; Brown, S.N.; Edwards, J.E.; Anil, M.H., and Fordham, D.P. (1992). Time in lairage needed by pigs to recover from transport stress. *Veterinary Record* **131**, 194–196.
- Weeding, C.M.; Hunter, E.J.; Guise, H.J.; Penny, H.C. (1993) Effects of abattoir and slaughter handling system on stress indicators in pig blood. *Veterinary Record* **113**, 10–13.
- Wenzlawowicz, M.V.; Schutte, A.; Hollenbon, K.V.; Altrock, A.V.; Bostelman, N.; Roeb, S. (1999) Field study on the welfare of meat quality aspects of Midas pig stunning device. *Fleischwirtschaft* **2**, 8–13.
- White, R.G.; DeShazer, J.A.; Tressler, C.J.; Borchert, G.M.; Davey, S.; Warning, A.; Parkhurst, A.M.; Milanuk, M.J.; Clems, E.T. (1995) Vocalizations and physiological response of pigs during castration with and without anesthetic. *Journal of Animal Science* **73**, 381–386.
- Wotton, S.B.; Gregory, N.G. (1986) Pig slaughtering procedures: Time to loss of brain responsiveness after exsanguination or cardiac arrest. *Research in Veterinary Science* **40**, 148–151.